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A PERTURBATIVE QCD BASED STUDY OF POLARIZED NUCLEON STRUCTURE IN THE TRANSITION REGION AND BEYOND: "QUARKS, COLOR NEUTRAL CLUSTERS, AND HADRONS"

S. LIUTI

Department of Physics
382, McCormick Rd.,
Charlottesville, VA 22904-4714, USA
E-mail: sl4y@virginia.edu

N. BIANCHI AND A. FANTONI

INFN, Laboratori Nazionali di Frascati
Via Enrico Fermi 40,
00044 Frascati (Roma) Italy
E-mail: fantoni@lnf.infn.it, bianchi@lnf.infn.it

A large fraction of the world data on both polarized and unpolarized inclusive ep scattering at large Bjorken x lies in the resonance region where a correspondence with the deep inelastic regime, known as Bloom and Gilman's duality, was observed. Recent analyses of the Q^2 dependence of the data show that parton-hadron duality is inconsistent with the twist expansion at low values of the final state invariant mass. We investigate the nature of this disagreement, and we interpret its occurrence in terms of contributions from non partonic degrees of freedom in a preconfinement model.

1. Introduction

Parton-hadron duality, or the idea that the outcome of any hard scattering process is determined by the initial scattering process among elementary constituents – the quarks and gluons – independently from the hadronic phase of the reaction, is a well rooted concept in our current view of high energy phenomena. The cross sections for both inclusive and semi-inclusive hadronic processes factor out into a "short distance" ($<<$ hadronic size) perturbatively calculable part, and a "large distance" ($\approx$ hadronic size) measurable part that is directly related to the quarks and gluons distribution inside the hadrons. During the scattering process the partons are essen-

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tially "free" – modulo perturbative-QCD (pQCD) radiation – the trasmo-grification of partons into hadrons and vice-versa happening at a much too large time scale to influence the outcome of the reaction. Essentially, all hadronic reactions, from $e^+e^- \to$ hadrons, to Deep Inelastic Scattering (DIS), to high energy hadron-hadron reactions are interpreted using this concept. Another aspect of duality, Bloom and Gilman (BG) duality [1], is the observation that by lowering the center of mass energy of the hard scattering process, *i.e.* by considering the production of resonances, the cross section follows in average a curve similar to the DIS one. The implications of BG duality are twofold: on one side the production of resonances seems to be still influenced by partonic degrees of freedom; on the other, the correlation functions encoding the non-perturbative structure of the proton might have a common origin with the ones in the resonance region.

A particularly interesting result was found in studies of inclusive reactions with no hadrons in the initial state, such as $e^+e^- \to$ hadrons, and hadronic τ decays [2]. It was pointed out that, because of the truncation of the PQCD asymptotic series, terms including quark and gluon condensates play an increasing role as the center of mass energy of the process decreases. Oscillations in the physical observables were then found to appear if the condensates are calculated in an instanton background. Such oscillating structure, calculated in [2] for values of the center of mass energy above the resonance region, is damped at high energy, hence warranting the onset of parton-hadron duality. In this contribution we examine a related question, namely whether it is possible to extend the picture of duality explored in the higher Q^2 region [2], to the resonance region, or to the BG domain. A necessary condition is to determine whether the curve from the perturbative regime smoothly interpolates through the resonances, or violations of this correspondence occur. The latter would indicate that we are entering a semi-hard phase of QCD, where preconfinement effects [11] are present.

2. Breakdown of Factorization

BG duality is considered to be fulfilled if the extrapolation using PQCD evolution from high Q^2 and W^2 into the resonance region, agrees with the experimental data in this region. The accuracy of current data allows us to address the question of *what extrapolation from the large Q^2, or asymptotic regime the cross sections in the resonance region should be compared to.* In order to best address possible ambiguities in the analyses due the choice of an "averaging procedure" for the data in the resonance region, one should
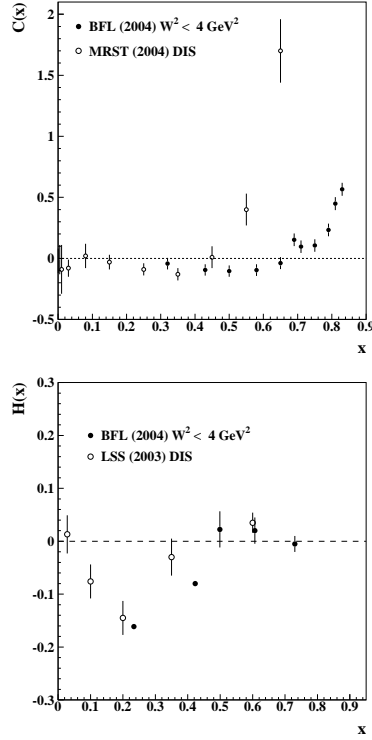
Figure 1. Comparison of HT contributions for both the structure function F_2 (upper panel) and the polarized structure function g_1 (lower panel) in the DIS and resonance regions, respectively. The full circles are the values obtained in the resonance region [6]. For F_2 these are compared with extractions using DIS data, from different collaborations: MRST (unpolarized) [8]. For g_1 they are compared to the extraction from [9]. Notice that we show our results in a factorized model for F_2, and in a non-factorized one for g_1 for a consistent comparison with [7,8,9].

consider the following complementary methods:

$$I(Q^2) = \int_{x_{\min}}^{x_{\max}} F_2^{\mathrm{res}}(x, Q^2)\, dx \tag{1a}$$

$$M_n(Q^2) = \int_0^1 dx\, \xi^{n-1}\, \frac{F_2^{\mathrm{res}}(x, Q^2)}{x}\, p_n \tag{1b}$$

$$F_2^{\mathrm{ave}}(x, Q^2(x, W^2)) = F_2^{\mathrm{Jlab}}(\xi, W^2) \tag{1c}$$

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where F_2^{res} is evaluated using the experimental data in the resonance region [a]. In Eq.(1a), for each Q^2 value: $x_{\min} = Q^2/(Q^2 + W_{\max}^2 - M^2)$, and $x_{\max} = Q^2/(Q^2 + W_{\min}^2 - M^2)$. $W_{\min}$ and $W_{\max}$ delimit either the whole resonance region, *i.e.* $W_{\min} \approx 1.1$ GeV^2, and $W_{\max}^2 \approx 4$ GeV^2, or smaller intervals within it. In Eq.(1b), ξ is the Nachtmann variable [3], and $M_n(Q^2)$ are Nachtmann moments [3]; p_n is a kinematical factor [3]. The r.h.s. of Eq.(1c), $F_2^{\mathrm{Jlab}}(\xi, W^2)$, is a smooth fit to the resonant data [4], valid for $1 < W^2 < 4$ GeV^2; F_2^{ave} symbolizes the average taken at the $Q^2 \equiv (x, W^2)$ of the data.

Besides ambiguities in the averaging procedure, in principle any extrapolation from high to low Q^2 is fraught with theoretical uncertainties ranging from the propagation of the uncertainty on $\alpha_S(M_Z^2)$ into the resonance region to the appearance of different types of both perturbative and power corrections in the low Q^2 regime. A program to address quantitatively these sources of theoretical errors was started in [5,6]. In this contribution we present results on the extraction of the dynamical Higher Twist (HT) terms from the resonance region, and we compare them to results obtained in the DIS region [7,8,9]. A clear discrepancy marking perhaps a breakdown of factorization at low values of W^2 is seen for the unpolarized structure function, F_2 (upper panel). More data at large x are needed in order to draw conclusion for the polarized structure function, g_1.

An obvious conclusion is that in correspondence of the most prominent resonances, we enter the non-perturbative regime. The "snap-shot" picture of the proton's pointlike partonic configurations is replaced with a "blurred" image that encompasses a range of distance scales. Yet, the difference between the PQCD-based extrapolation from large Q^2, W^2 and the smooth average of the resonances can be considered to be small, as quantified by us in Fig.1. This motivated one of us (S.L.[10]) to model the low W^2 region by considering modified evolution equations along the line of the Bassetto-Ciafaloni-Marchesini (BCM) [11] equations that generate "preconfinement" in the hadronic phase of high energy processes. BG duality and its violations, can then be explained in terms of the mass distribution of Color Neutral clusters of quarks and gluons that characterize the semihard phase.

3. Conclusions and Outlook

We investigated the phenomenon of parton-hadron duality for inclusive unpolarized and polarized ep scattering. Our conclusions are as follows: *i)*

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[a]Similar formulae hold for the polarized structure function, g_1.

Bloom and Gilman duality can now be studied quantitatively, because of the increased accuracy of the data; *ii)* We interpret the "apparent agreement" between data and the pQCD curve in the resonance region as a signature of a breakdown of the twist expansion at low W^2. The HTs extracted from the resonance region are in fact both in qualitative and quantitative disagreement with the ones extracted from DIS; *iii)* BG duality needs to be treated distinctively from parton-hadron duality at higher Q^2 and center of mass energy values. The Q^2 dependence in the Few GeV region can be modeled by considering the preconfinement property of QCD, as a hybrid phase where clusters of color connected partons interact directly with the probe.

As an outlook, the 12 GeV program at Jefferson Lab, will enable us to validate the picture behind duality and its different manifestations, by addressing quantitatively a variety of reactions: from polarized scattering at large x and W^2, to semi-inclusive experiments ...

Acknowledgments

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